AEROSPACE REPORT NO.
TOR-2009(8550)-9194

# Software Technology Readiness Assessments: Service-Oriented Architecture (SOA) as a Critical Technology Element in Ground Systems

15 July 2009

Peter Hantos
Software Acquisition and Process Department
Software Engineering Subdivision

Prepared for:

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Contract No. FA8802-09-C-0001

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AEROSPACE
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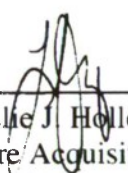
Approved by:



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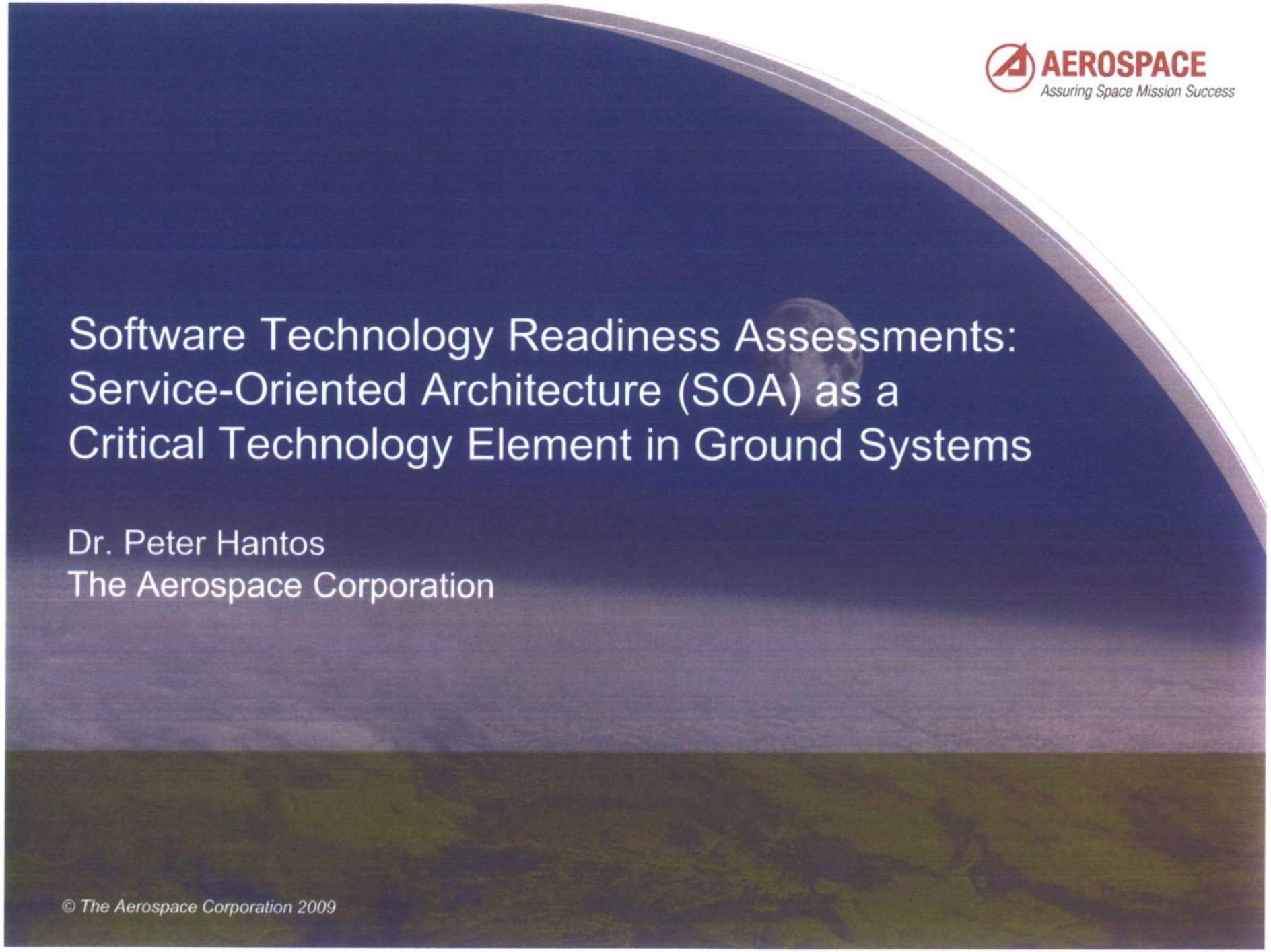


# Software Technology Readiness Assessments: Service-Oriented Architecture (SOA) as a Critical Technology Element in Ground Systems

Dr. Peter Hantos
The Aerospace Corporation

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  - *Reviewers*
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# Contents

# Introduction

- Why is Technology Readiness Assessment important?
  - *"The inability to define and thus measure technology readiness facilitates decisions to incorporate immature technology in system design at Milestone B which consequently leads to technical problems during System Design and Development." [DAPA 2006]*
- Why is it necessary to discuss SOA?
  - *Google produced 40 million (!) hits in 0.2 sec for "SOA". Even if we discount hits on the Society of Actuaries and such, it is very impressive. Wouldn't it prove that it is a mature technology?*
  - *No. Using SOA is a risky proposition and extreme caution is needed. SOA belongs to the category where to determine the maturity of the technology, concepts and new code, reuse, and Commercial-Off-the-Shelf (COTS) dimensions all might have to be evaluated.*

# Technology Readiness Assessments – the 64,000-foot View

- Public Law 109-163-Jan.6, 2006, Section 801

  **TITLE VIII—ACQUISITION POLICY, ACQUISITION MANAGEMENT, AND RELATED MATTERS**

  ***Subtitle A—Provisions Relating to Major Defense Acquisition Programs***

  ***SEC. 801. REQUIREMENT FOR CERTIFICATION BEFORE MAJOR DEFENSE ACQUISITION PROGRAM MAY PROCEED TO MILESTONE B.***

  *(a) CERTIFICATION REQUIREMENT.—Chapter 139 of title 10, United States Code, is amended by inserting after section 2366 the following new section:*

  ***"§ 2366a. Major defense acquisition programs: certification required before Milestone B or Key Decision Point B approval***

  *(a) CERTIFICATION.—A major defense acquisition program may not receive Milestone B approval, or Key Decision Point B approval in the case of a space program, until the milestone decision authority certifies that—*

  ***(1) the technology in the program has been demonstrated in a relevant environment; …"***

- November 2, 2007 Air Force Memorandum on Technology Certification
  - *Spells out that for all Critical Technology Elements (CTEs) it has to be demonstrated in a relevant environment that they are at Technology Readiness Level (TRL) 6* or greater.*

* *DOD TRL rating scheme is shown later*

# Basic Department of Defense (DOD) TRA Definitions*

- Technology Maturity
  - *A measure or degree to which proposed technologies meet program objectives*
- Technology Readiness Assessment
  - *A TRA is a systematic, metrics-based process and accompanying report that assesses the maturity of certain technologies used in systems. The TRA is not intended to predict future performance of the evaluated technologies, nor does it assess the quality of the system architecture, design, or integration plan*
- Relevant Environment
  - *Relevant Environment is a validation environment that simulates key aspects of the Operational Environment*
- TRA is different from "Conventional" Risk Management
  - *The result of a TRA is a single number on a 1-9, ordinal scale, called Technology Readiness Level (TRL).*
  - *TRLs do not intend to reflect either the likelihood of attaining required maturity or the impact of not achieving the required maturity*

* *Source: [DOD 2005]*

# Assessing CTEs using the TRL "Thermometer"


- TRL 9: Actual system proven through successful mission operations
- TRL 8: Actual system completed and qualified through test and demonstration
- TRL 7: System prototype demonstration in an operational environment
- TRL 6: System/subsystem model or prototype demonstration in a relevant environment
- TRL 5: Component and/or breadboard validation in relevant environment
- TRL 4: Component and/or breadboard validation in laboratory environment
- TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept
- TRL 2: Technology concept and/or application formulated
- TRL 1: Basic principles observed and reported

# Critical Technology Elements

- Context
  - *Note the reference to "certain" technologies in the earlier TRA definition*
    - The technologies that are subject of a TRA will be called Critical Technology Elements (CTEs)
  - *The analysis of candidate technologies begins even before Concept Decision takes place for the acquisition*
- Critical Technology Element Defined
  - *The DOD TRA deskbook offers a series of 8 questions to determine if a technology element is critical*
    - **The focus of this paper is to discuss the answers to these questions**

# CTE Identification Questions

1) Does the software technology directly impact an operational requirement?
2) Does the software technology have a significant impact on an improved delivery schedule?
3) Does the software technology have a significant impact on the affordability of the system?
4) If this is a spiral development, is the software technology essential to meet the spiral deliverables?

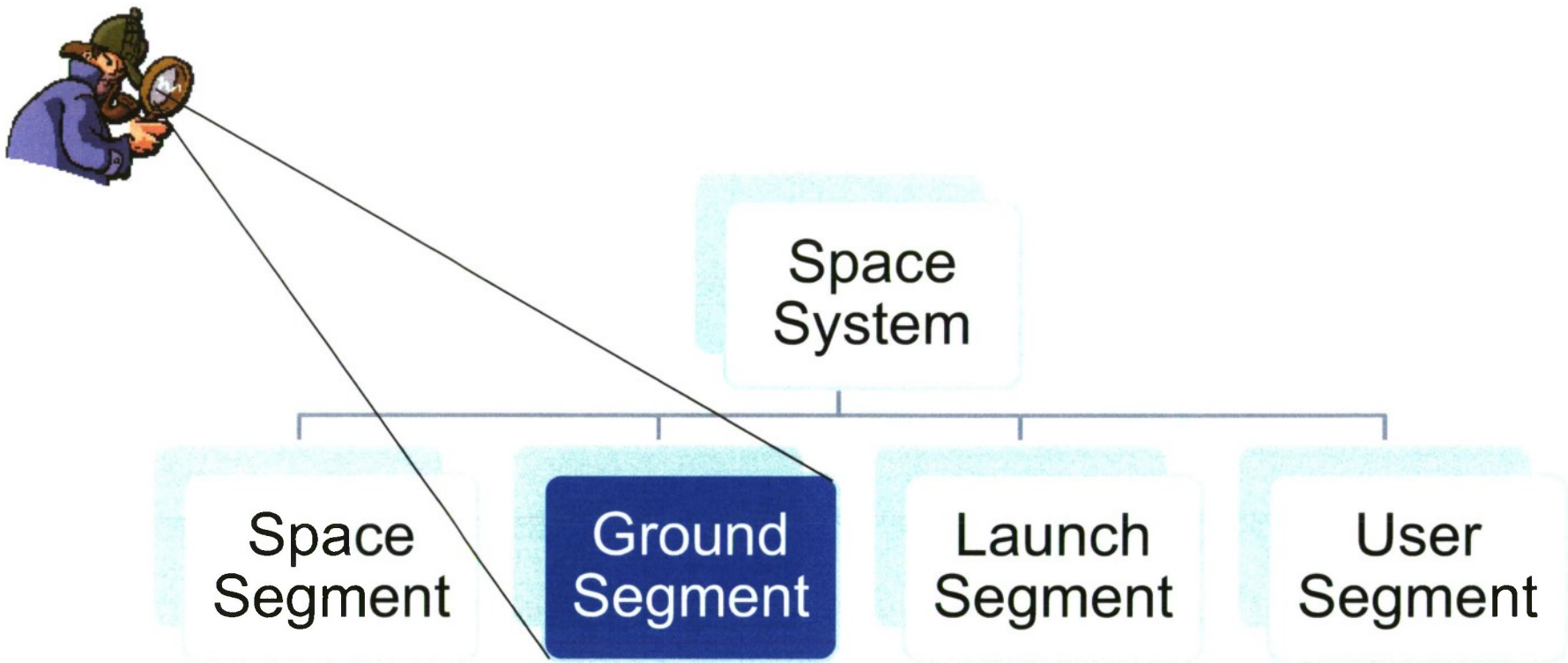
---

5) Is the technology new or novel?
6) Has the technology been modified?
7) Has the software technology been repackaged such that a new relevant environment is realized?
8) Is the software technology expected to operate in an environment and/or achieve a performance beyond its original design intention?

---

** Source: [DOD 2005], p 3-7. For a technology to be critical, the answer to at least one of the first four questions and one of the last four questions must be "yes".*

# SOA as a CTE in a Ground System



# What is a Service-Oriented Architecture?

- Architecture*
  - *"Architecture is the fundamental organization of a system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution."*
- Service-Oriented Architecture**
  - *"A Service-Oriented Architecture takes advantage of networking capabilities to integrate applications in a way that is independent of architecture, programming language, development platform and vendor. Through a set of standard interfaces, services are made available to any consumer willing to follow the rules for interface and consumption."*
- Selected, generic SOA services
  - *Messaging, mediation/translation between data structures and protocols, Data Base Management System (DBMS), high-speed networking, collaboration, Information Assurance/Security, etc.*
- Question to ponder
  - *What do you think the benefits of using such an architectural style are?*

* *Source: [IEEE 2000]*

** *Source: [Minkiewicz 2007]*

# The Road to SOA for Space

- SOA is a promising approach to implement Operationally Responsive Space (ORS) and Joint Warfighting Space (JWS)
- Operationally Responsive Space*
  - *ORS is characterized by an incremental approach from prototyping to production, on the basis of highly modularized capabilities*
  - *According to the early ORS ideas, the key to achieving these objectives is space system bus standardization*
    - Note that the term "bus" in ORS equally relates to all segments of a space system, not only to the space vehicle.
- Joint Warfighting Space [Schuler 2005]
  - *The JWS initiative seeks to make space an organic part of joint task forces in theater - ORS is an enabler of JWS*
- There is an inherent synergy between ORS and Network-Centric Warfare (NCW)
  - *NCW, via the Network Centric Infrastructure (NCI), is an enabler of ORS*
    - It will be shown later how SOA supports NCW/NCI

** ORS was originally introduced by the now defunct Office of Force Transformation (OFT) DOD entity. Here we only refer to the generic aspects of the earlier OFT proposal.*

# Selected SOA Services for a Ground System

- Sample Ground functionality that may be implemented via services*
  - *Command Processing*
    - Commands to space vehicles
    - Commands to antennae systems
  - *Orbital Data Processing*
  - *Critical alarms*
  - *Mission Planning*
  - *Real-time Telemetry Processing*
  - *Processing/providing data on external interfaces*
    - Other ground stations
    - External clients of ground station services
  - *Situational awareness*
  - *Etc.*
- Of course a SOA Framework would be needed as well
  - *E.g., to implement the registry that facilitates the seamless integration, upgrade, discovery and invocation of services*

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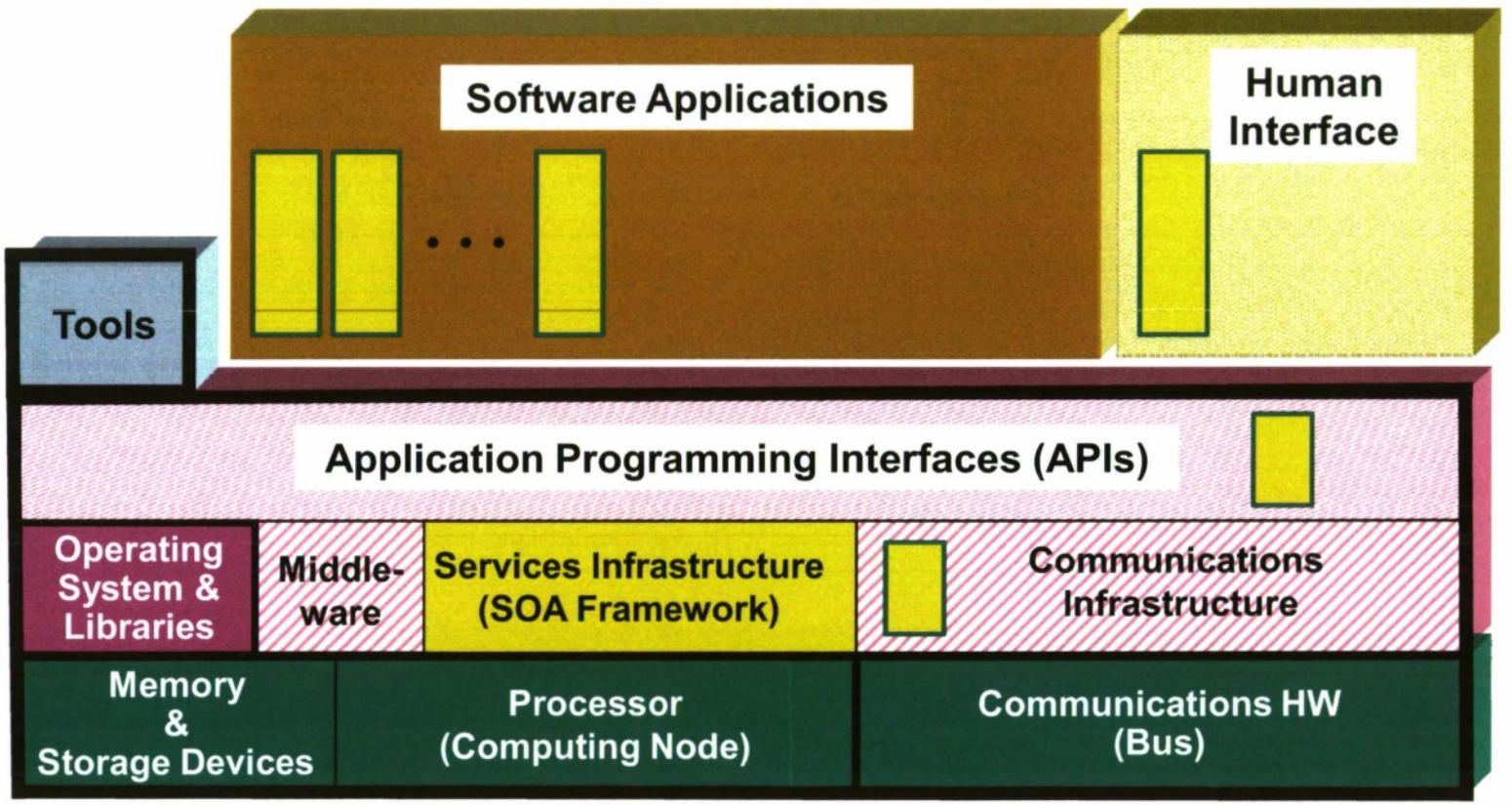
** Caveat: SOA does not always make sense for implementing all Ground System functionality*

# SOA Components in a Ground System




***Legend:*** *Potential SOA Component*

*Note that this simple GS example does not have HW input/output elements other than the bus*

# CTE Identification Question 1

(1) Does the software technology directly impact an operational requirement?

- *In case of ground systems the answer is definitely **YES**, due to Network Centric Warfare (NCW) and DOD SOA directive implications*
  - NCW is a state-of-the art war-fighting theory with the following, two implementation dimensions
    - Network Centric Operations (NCO), dealing with the cognitive and social dimensions of NCW
    - Network Centric Infrastructure (NCI), addressing physical and information dimensions of NCW
  - *Note that NCW almost automatically puts every weapon system in a System of Systems (SOS) context*
  - SOA may be used to implement NCI and it is strongly promoted* by the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics (OUSD(AT&L))

* *Source: [OUSD 2008]*

# CTE Identification Questions 2-3

(2) Does the software technology have a significant impact on an improved delivery schedule?

- ***YES***. *Service orientation addresses numerous aspects/enablers of improving the delivery schedule*
  - The framework and core building blocks can be acquired as COTS
    - *A properly designed SOA framework enables the automatic discovery of fine-grained software services, negotiates their acquisition, and composes, binds, executes, and unbinds them*
  - The use of SOA speeds-up the incremental delivery of new capabilities in the system evolution context
    - *Through loose coupling and tight interface standards, consumers of services need only know how to interact with a service, and there is no need to understand deeper details*

(3) Does the software technology have a significant impact on the affordability of the system?

*- Most likely **NO**.*

# CTE Identification Questions 4-6

(4) If this is a spiral development, is the software technology essential to meet the spiral deliverables?

- *This question cannot be answered without knowing the actual acquisition strategy and plans for the system to be acquired. However, it has to be noted that if the system architecture is SOA-based then all infrastructure elements and the SOA framework must be in place before even one service could be delivered.*

(5) Is the technology new or novel?

- ***NO**. Do you remember Distributed Object Architecture (DOA), Common Object Model (COM), Object Request Broker (ORB), Common Object Request Broker Architecture (CORBA), etc.?*

(6) Has the technology been modified?

- *It depends. Most likely the answer is **NO**, because the SOA COTS elements would not be modified.*

# CTE Identification Questions 7-8

(7) Has the software technology been repackaged such that a new relevant environment is realized?

- *"Repackaging" is a broad term, and involves considerations for both the hardware platform and system software platform of the SOA services. This question is particularly critical when services are individually adopted for the objective system*

(8) Is the software technology expected to operate in an environment and/or achieve a performance beyond its original design intention?

- *One of the main concerns with SOA implementations is the overhead associated with service invocation and execution, and consequently, with performance or Quality of Service (QoS). It is very unlikely that the structure of the objective system, the nature and number of services would be identical to a prior system that is already in use (i.e., it would qualify for TRL 9), consequently the answer to this question is most likely* ***YES****.*

# Evaluation of Answers

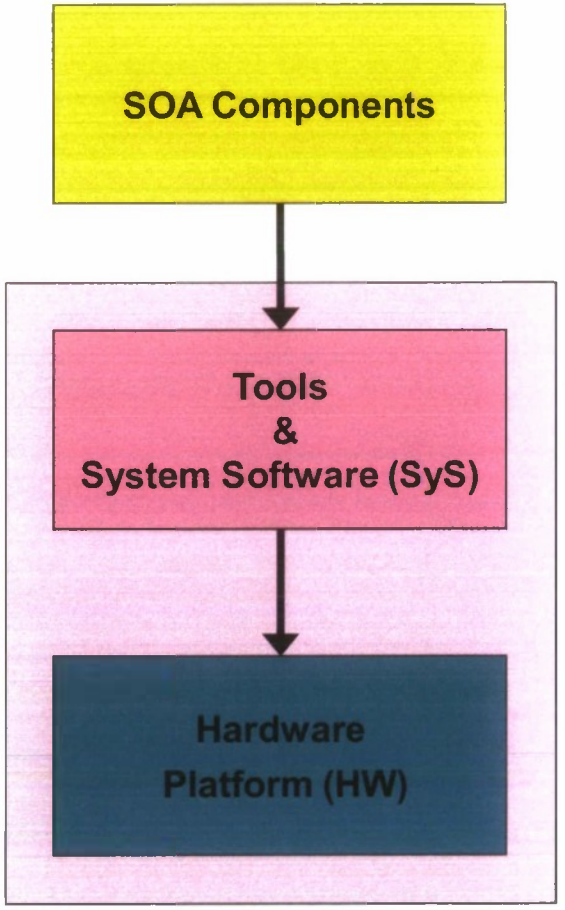
1) Does the software technology directly impact an operational requirement? **YES**
2) Does the software technology have a significant impact on an improved delivery schedule? **YES**
3) Does the software technology have a significant impact on the affordability of the system? **NO**
4) If this is a spiral development, is the software technology essential to meet the spiral deliverables? **Maybe**
5) Is the technology new or novel? **NO**
6) Has the technology been modified? **NO**
7) Has the software technology been repackaged such that a new relevant environment is realized? **Maybe**
8) Is the software technology expected to operate in an environment and/or achieve a performance beyond its original design intention? **YES**

*Conclusion: Due to **YES** answers to questions 1, 2, and 8, SOA is a CTE.*

# Technology Readiness Assessment Considerations

- Beyond the issues highlighted in the previous set of questions, special attention has to be paid to the following specifics:
  - *Platform/Relevant Environment compatibility for COTS SOA elements*
    - Note that different services might come from different sources
  - *Inter-component Compatibility of acquired COTS SOA elements*
    - See reason given at the prior issue
  - *Execution performance considerations and scaling of services*
    - SOA involves a lot of overhead; the impact needs to be carefully assessed in advance
  - *SOA interface adequacy for new services*
    - Service uniformity is achieved via standard interfaces; however, beyond the core functionality, the inherent throughput, data capacity, error tolerance, testability, etc. might not be enough for the new service.
  - *Feasibility and effort needed to interface reused and legacy software*
    - As it was mentioned earlier, only selected functionality would be provided as a "service"

# SOA Component Dependency from a TRA Perspective




**TRL(SOA) ≤ TRL(TOOLS) ≤ TRL(SyS) ≤ TRL(HW)**



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# COTS/Reuse Perspective on SOA*

- The application of COTS/Reused Software in general is a very attractive but also very risky approach to software development
  - *However, with respect to SOA, we need clarity on what COTS/Reuse Assessment Attributes are in-scope for a TRA and what inquiries should belong to the "routine", programmatic risk management area*

- In-scope for TRA
  - *Accuracy, correctness*
  - *Availability*
  - *Robustness*
  - *Security*
  - *Product performance*
  - *Testability*
  - *Version compatibility*
  - *Inter-component Compatibility*
  - *Functionality*

In-scope for Trades and Risk Reduction

- *Documentation quality*
- *Ease of Use*
- *Flexibility*
- *Installation/Upgrade Ease*
- *Portability*
- *Price*
- *Vendor support and maturity*
- *Training*
- *Vendor concessions*

** Note that the assessment of evaluation, glue code writing, and integration effort (cost and schedule) is also out of scope for a TRA while it is a very critical planning activity.*

# Conclusion

- Technology Readiness Assessment is a critical tool in Defense Acquisition; also, it is mandated by Public Law
- Modern weapon systems (including all space systems) are software-intensive, technology-driven systems; consequently, the early evaluation of software technologies is essential
- SOA is a promising, emerging software architecture style, offering numerous benefits but also substantial challenges and risks
- SOA definitely qualifies as a Critical Technology Element, and as such must be subjected to a rigorous Technology Readiness Assessment inquiry
- At the time writing this paper, SOA is only considered for Ground Systems. However, research to develop real-time SOA is on its way, so stay tuned …

# Acronyms

| | |
|---|---|
| **AT&L** | Acquisition, Technology, and Logistics |
| **COM** | Component Object Model |
| **CORBA** | Common Object Request Broker Architecture |
| **COTS** | Commercial Off-the-Shelf |
| **CTE** | Critical Technology Element |
| **DAPA** | Defense Acquisition Performance Assessment |
| **DBMS** | Data Base Management System |
| **DOA** | Distributed Object Architecture |
| **DOD** | Department of Defense |
| **GS** | Ground System |
| **HW** | Hardware |
| **JWS** | Joint Warfighting Space |
| **MOIE** | Mission-Oriented Investigation and Experimentation |
| **NCI** | Network Centric Infrastructure |
| **NCO** | Network Centric Operations |
| **NCW** | Network Centric Warfare |
| **OFT** | Office of Force Transformation |
| **ORB** | Object Request Broker |
| **ORS** | Operationally Responsive Space |
| **OUSD** | Office of the Under Secretary of Defense |
| **QoS** | Quality of Service |
| **SMC** | Space and Missile Systems Center |
| **SOA** | Service-Oriented Architecture |
| **SyS** | System Software |
| **TRA** | Technology Readiness Assessment |

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